

AUTOMATIC DETERMINATION OF LAMINATED SALIENT-POLE SYNCHRONOUS MACHINES PARAMETERS BASED ON THE FINITE ELEMENT METHOD

Dr. M. Tu Xuan, C. Ramirez, Dr. B. Kawkabani, Prof. J.J. Simond,

Swiss Federal Institute of Technology, Electrical Engineering Dept.,
CH-1015 Lausanne, SWITZERLAND

Fax: 4121-6932687; e-mail: Mai.TuXuan@epfl.ch

Abstract: The present paper presents an automatic approach for the determination of the parameters of laminated salient-pole synchronous machines, based on 2D finite element method (FEM). Calculations using FEM are performed in rotation (sudden three-phase short-circuit) and at standstill, for different positions of the rotor and for different frequencies. A comparison between results obtained by both methods is presented.

1.- INTRODUCTION

The study of the behavior of synchronous machine in steady-state or transient conditions requires an accurate knowledge of the equivalent circuit parameters and of the characteristic values of the machine. Usual standards recommend different tests on a platform in order to determine these parameters: tests at standstill and sudden three-phase short-circuit with a reduced voltage applied at the terminals of the machine before the short-circuit. The goal of the present study is to realize a 'numerical test platform' based on 2D FEM calculations destined to replace the costing and hazardous tests of a conventional test platform, and to develop this way a powerful tool for the design and optimization of medium and large synchronous and induction machines. Figure 1 shows the general approach of a numerical test platform in order to determine the equivalent circuits and the characteristic values by FEM calculations. The present paper is the first step of this general study and concerns the analysis of the results at standstill and the sudden three-phase short-circuit of a laminated salient-pole synchronous machine, without taking into account saturation effects. Calculations are performed on a machine with $S_n = 2.3$ MVA rated power, and $U_n = 5.7$ kV rated voltage, in rotation (sudden three-phase short-circuit at the terminals of the stator), and at standstill, for different positions of the rotor and for different frequencies. This step is realized in order to compare these two approaches and to verify the precision

of different algorithms. A further step would be to take into account saturation effects, and to determine the subtransient direct-axis reactance of the synchronous machine for applied voltages at the terminals of the machine before the short-circuit $U \geq U_n$, tests which are not possible in a conventional test platform. The extension of the study to massive rotors is also considered. A special attention has been devoted to the automatic determination of different parameters either by FEM calculations or by the post-processing approaches.

Even though FEM softwares are user friendly, a great deal of time can be saved by using a program that generates command files to introduce geometric data automatically. The drawing for one or two salient poles synchronous machines is created according to an established list of geometrical parameters (fig.2), which fully determines the geometry of the machine. The automatic assignment of physical properties to different regions, as well as the definition of the electrical circuit associated with the machine's operating mode, offer the user more facility.

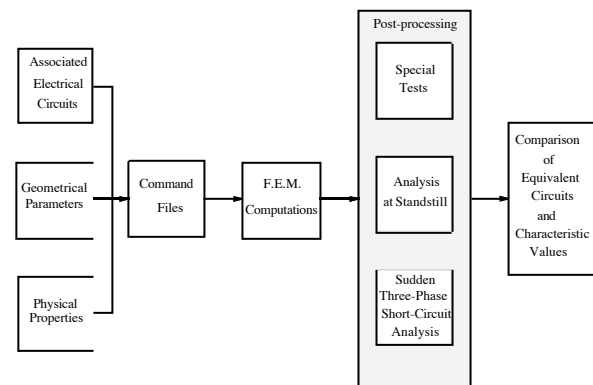


Figure 1: General approach for a numerical test platform.

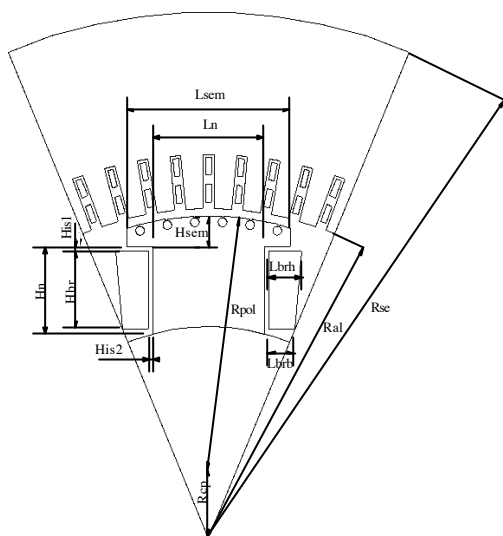


Figure 2

2. -SUDDEN THREE-PHASE SHORT-CIRCUIT FEM COMPUTATIONS

2.1.- Model

A sudden three-phase short-circuit has been simulated in transient magnetic [1]. The electric circuit related to this case is shown in figure 3. One can notice the armature, the excitation and the damper circuits.

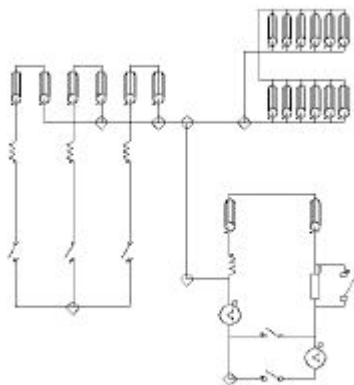


Figure 3: Electrical circuit related to a sudden three-phase short-circuit.

2.2.- Analysis of results

Figure 4 represent the distribution of the magnetic field 25 ms after the short-circuit.

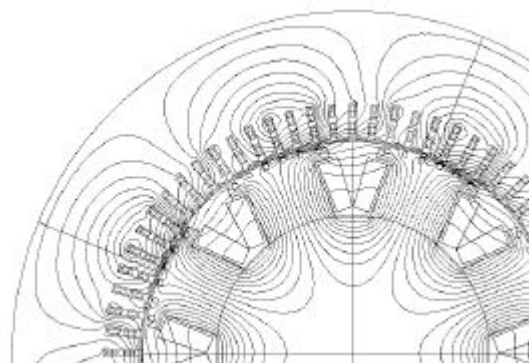


Figure 4: Distribution of the magnetic field, 25 ms after the short-circuit

Figures 5 and 6 show the 'a' phase current as well as the excitation current during the short-circuit, while the machine is initially unloaded ($u_o = 0.25$ p.u.). A program of identification of the parameters of a synchronous machine permits the automatic analysis of the three-phase currents obtained in this case and the determination of different transient and subtransient reactances and time constants (fig. 7). The automatic analysis of the excitation current [2] provides, in addition to the cited values, an accurate definition of all the parameters of the equivalent circuit of a synchronous machine in the direct-axis (fig. 8).

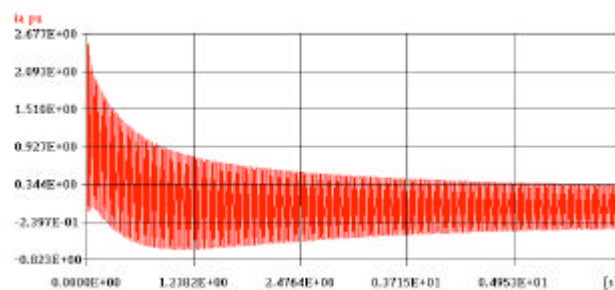


Figure 5: ‘a’ phase current during the short-circuit

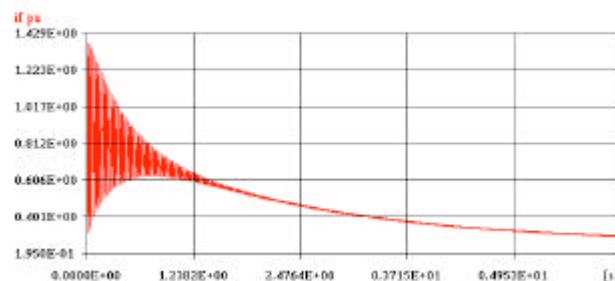


Figure 6: Excitation current during the short-circuit (the synchronous machine initially unloaded ($u_o = 0.25$ p.u)).

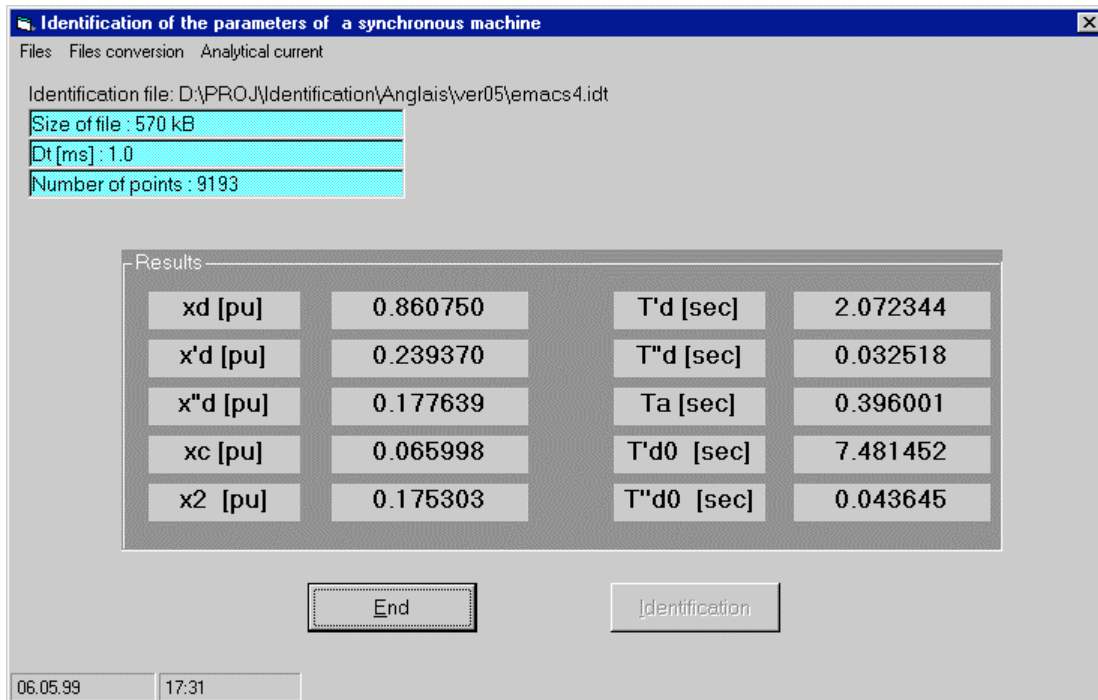


Figure 7: Identification of the parameters of a synchronous machine

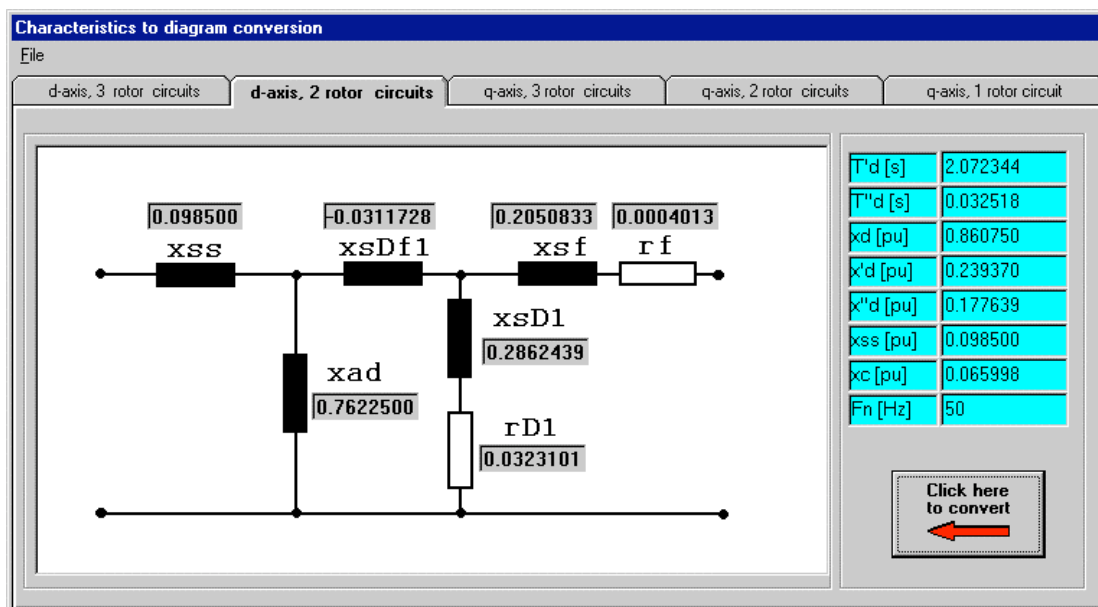


Figure 8: Conversion of the parameters of a synchronous machine

3.- FEM COMPUTATIONS AT STANDSTILL

3.1.- Model

FEM computations at standstill are realized in magnetodynamic. Two phases are supplied by a sinusoidal voltage at a given frequency, the excitation circuit short-circuited and the rotor locked in the direct or quadrature axis (fig. 9).

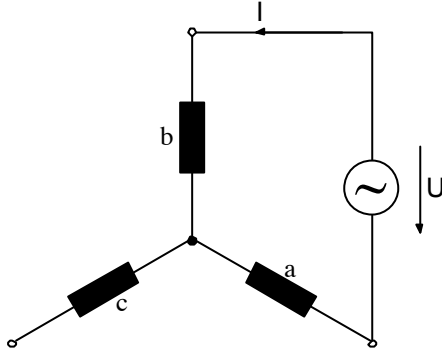


Figure 9: Supply with a single sinusoidal voltage at standstill

3.2.- Analysis of results

One has:

$$Z_d = U/2I \quad (1)$$

Figures 10 and 11 represent the distribution of the magnetic field at standstill (rotor locked in the direct-axis), with the excitation circuit short-circuited for $f=0.01$ Hz, respectively 100 Hz.

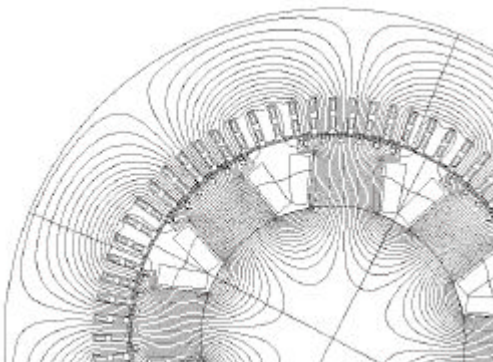


Figure 10: Distribution of the magnetic field with rotor locked in the direct-axis, excitation circuit short-circuited ($f=0.01$ Hz).

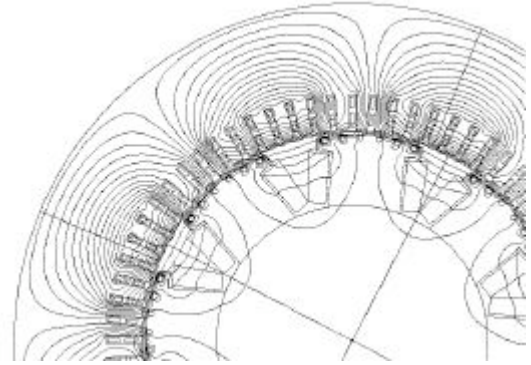


Figure 11: Distribution of the magnetic field with rotor locked in the direct-axis, excitation circuit short-circuited ($f=100$ Hz).

4.- COMPARISON OF RESULTS

Based on the equivalent circuit identified from the three-phase short-circuit test (fig. 8), the current locus curve in the direct-axis ($1/Z_d$) expressed in per unit is calculated analytically for different frequencies and represented in figure 12. One can notice good agreement between results obtained by the two methods.

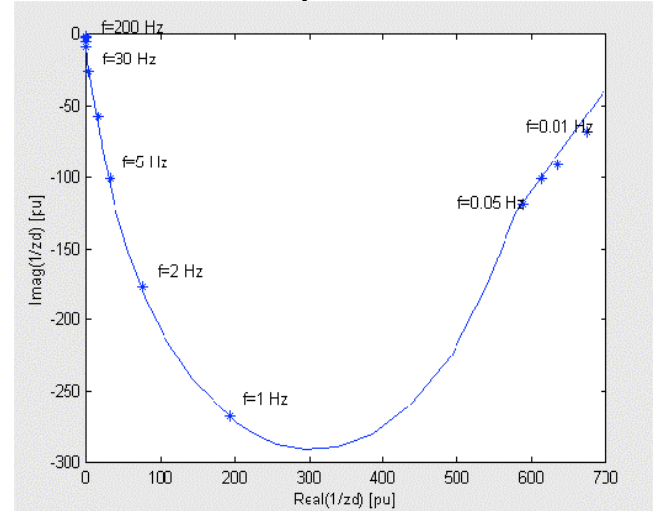


Figure 12: Current locus curve in the direct-axis
--- short-circuit results
* results at standstill

Table 1: Comparison of results

f [Hz]	Short-circuit		At standstill	
	Z_d [p.u]	ϕ [deg]	Z_d [p.u]	ϕ [deg]
1	0.0051	66.97	0.0052	66.52
5	0.0204	77.14	0.0167	74.64
10	0.0373	81.48	0.0375	82.24
50	0.1781	88.06	0.1811	88.30
100	0.3555	89.03	0.3618	89.15

Table 1 shows the results obtained by both methods in the direct-axis.

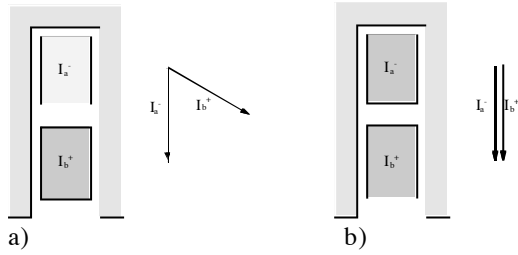


Figure 13: Computations at standstill
a): supply with a three-phase sinusoidal voltage
b): supply with a single sinusoidal voltage

The difference noticed in the results obtained by both methods results from the mode of supply at standstill. Indeed, if we consider a slot of the stator with two conductors belonging to phases a and b, for a supply at standstill with a single sinusoidal voltage as mentioned in figure 9 the phasors of the currents in the two conductors are represented in figure 13b. In fact, for a supply with a three-phase sinusoidal voltage, the currents are given by figure 13a. It is well-known that the armature leakage reactance is slightly lower in this case.

Figure 14 represents the current locus curve in the quadrature-axis calculated at standstill.

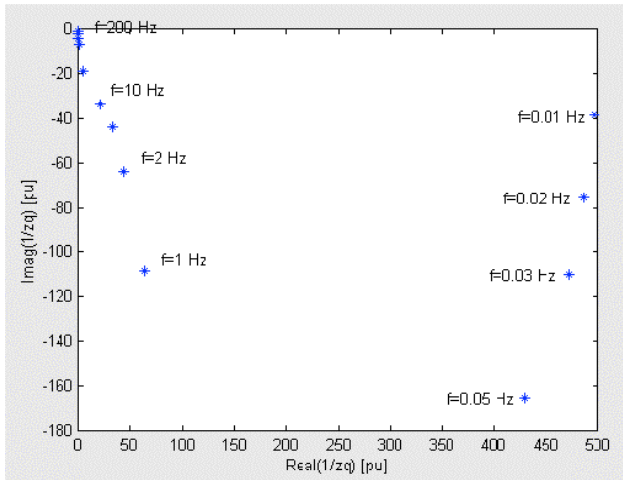


Figure 14: Current locus curve in the quadrature-axis
* results at standstill

5.- CONCLUSIONS

An automatic approach for the determination of the parameters of laminated salient-pole synchronous machines, based on 2D FEM, has been presented. A good agreement is obtained by the results at standstill and in rotation for the sudden three-phase short-circuit without considering saturation effects. The extension of this approach to salient-pole synchronous machines with massive rotors, turbogenerators and induction machines, is also considered. For turbogenerators, this automatic approach may be applied for the determination of sub-transient data.

References

- [1] FLUX2D, version 7.30, CEDRAT, 1998
- [2] Canay I.M.: Determination of model parameters of synchronous machines, Proc. IEE, vol. 130, Pt. B., No 2, 1983, pp. 86-94.

List of used symbols

- x_{ss} : armature leakage reactance
- x_d : direct-axis synchronous reactance
- x_{ad} : direct-axis magnetizing reactance
- x'_d : transient direct-axis reactance
- x''_d : subtransient direct-axis reactance
- x_c : characteristic reactance deduced from the excitation current. This reactance permits the precise determination of the mutual exclusive reactance x_{sDf1} between damper and excitation circuits
- x_2 : negative-sequence reactance
- r_f : excitation resistance
- x_{sf} : excitation leakage reactance
- r_{D1} : direct-axis damper winding resistance
- x_{sD1} : direct-axis damper winding leakage reactance
- T_a : armature short-circuit time constant
- T'_d : direct-axis transient short-circuit time constant
- T''_d : direct-axis subtransient short-circuit time constant
- T'_{do} : direct-axis transient open-circuit time constant
- T''_{do} : direct-axis subtransient open-circuit time constant